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Factors affecting longevity in maternal Duroc swine lines

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Abstract

A competing risks approach was used to evaluate the influence of several pre-farrowing factors on risk of culling due to different causes in Duroc swine, these having low fertility, low productivity, lameness and mortality. Culling due to low fertility increased for average daily gains during the growth test lower than 585 g/day, whereas culling due to low productivity and mortality increased with low levels of backfat thickness at the end of the growth test. Lesser loin depths at first farrowing reduced culling due to low productivity but increased culling due to lameness. Furthermore, a higher average daily gain from the end of the growth test to first mating increased culling by all causes. A complementary analysis was carried out to evaluate the influence of these factors on risk of culling without taking into account the specific reason of failure. In this second analysis, the factors were included as time-dependent covariates whose relative importance changed throughout the sows' productive life. Expected survival functions and replacement rates have been calculated in different hypothetical situations in order to determine the optimal animal body type at first farrowing to maximise longevity, which under our production conditions is independent of average daily gain from birth until the end of the growth test, but from the end of the growth test to first mating average daily gain should not be over 485 g/day; backfat thickness should be more than 16 mm at the end of the growth test and maintain this level until the first parturition without exceeding 19 mm; loin depth should be kept below 45 mm at first farrowing.

Keywords: Longevity; Survival analysis; Competing risks; Sow productivity; Duroc swine; Maternal lines

1. Introduction

During the last several years, culling rates of breeding females have climbed to levels approaching 50%. Increased sow mortality, combined with reproductive problems such as failing to cycle in a timely manner, not conceiving, not farrowing, poor performance or physical problems (e.g., lameness) are the major reasons for this increase in replacement rates in commercial sow units (Dial and Koketsu, 1996; Friendship et al., 1996). These high replacement rates result in the need for larger gilt pools and therefore the purchase or production of more breeding gilts. Apart from the cost associated with the mentioned purchases, the producer has to incur further expenses related to the acclimati-

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sation of the new gilts and face the risk of introducing new diseases. Furthermore, high replacement rates may be associated with animal welfare, since some of the causes of culling could be indicators of a welfare compromise for the animals involved (Barnett et al., 2001). A better knowledge of the causes of culling would be useful when providing practical recommendations for the management of gilts in order to increase their productive lifespan.

Productive life span is a trait which has received increasing attention in animal breeding. Ducrocq (1997) has proposed a general strategy for the analysis of a productive life span based on the survival analysis as an adequate method for the genetic evaluation of the length of productive life measurements. In particular, a semiparametric proportional hazards model (Cox, 1972) is usually used to investigate the influence of different covariates on the risk of culling. However, sows being culled for different causes are certainly affected by a distinct set of covariates or by the same covariates in different degrees (Dürr et al., 2002). When causes of failure are of interest and must be accounted for in the analysis, the method of competing risks (Kalbfleisch and Prentice, 1980) offers an intuitive but powerful way of handling survival times. The general concept underlying competing risks analysis is that the occurrence of one type of cause of failure removes the individual from risk of all other causes. In this case, the type-specific hazards can be obtained in the same way as the non-specific hazard function by just regarding all failures of types other than the recorded cause of failure as censored at the individual's failure time (Allison, 1995).

Different aspects of survival analysis applied to sows have been discussed in the literature, but in most cases the cause of failure is not taken into consideration. As explained before, one factor could have a great effect on culling due to a particular cause and no effect on another. Therefore, the effect of this factor on non-specific culling is a balance of its effect on each cause-specific culling. As the relative importance of each cause in this balance is different throughout a sow's productive life, the effect of the factor on culling may also be different throughout her productive life, suggesting a time-dependent survival analysis.

The first aim of this study is to evaluate the influence of several pre-farrowing factors on cause-specific hazards in maternal Duroc swine by a competing risk approach. These factors were average daily gain from birth to the end of the growth test and from this test to first mating, backfat thickness at the end of the growth test and at first farrowing, and loin depth at first farrowing. After estimating all of the cause-specific hazards, we have established the dependence of the non-specific hazard function (mixture of all the cause-specific hazards) on the mentioned factors using a time-dependent proportional hazards model. This analysis allowed us to estimate the expected survival functions in different hypothetical situations accounting for this dependence, as well as replacement rates in order to determine the optimal animal body type at first parturition to maximize longevity.

2. Material and methods

2.1. Animals

A total of 467 Duroc purebred gilts from Selección Batallé S.A. were used for this study. These gilts founded a new nucleus herd in 1999. At the end of the growth period (at 167 days of age on average), the gilts weighed 96.2 kg on average. During the period from the end of the test to the first mating, the gilts were fed a restricted concentrate diet (2 kg/day) containing 16.65% crude protein, 0.73% digestible lysine and 2995 kcal/kg ME. All gilts were mated within a 5-month period. At first effective mating, gilts weighed 133.8 kg on average and were 257 days old. Average age at first farrowing was 372 days.

Gilts were weighed at the end of the growth period and at first mating. These measurements were used to calculate average daily gains from birth to the end of the growth test (ADGt) and from the end of the growth test to first mating (ADGm). Backfat thickness was measured at the last rib level (P2) at the end of the growth test (BFt) and at first farrowing (BFf) using ultrasound equipment (Piglog 105, SFK®, Denmark). In addition, loin depth was also measured at the last rib level (P2) using the same ultrasound equipment as at first farrowing (LDf).

2.2. Survival analysis

The length of the productive life t of a sow was calculated as the difference in days between the date of culling and the date at first farrowing. Culling criteria were the same throughout the experiment and similar to those of a commercial sow operation. Sows were culled due to low fertility, low productivity (prolificacy), lameness, mortality and other less frequent causes (not specified). A sow was culled due to low fertility after failing to cycle twice consecutively. After the third and subsequent weanings sows with an average litter size less than 7.5 piglets weaned were culled due to low productivity. Sows with signs of lameness were culled after weaning their piglets. Finally, the records of sows still alive at the end of the study (September 30th of 2002) were regarded as censored. After editing, our database included data on the productive life of 467 sows, with 353 complete records (75.6%) and 114 censored records (24.4%).

2.2.1. Competing risks analysis

The competing risks approach is of particular interest in the study of causes of disposal in swine. Only the disposal causes (specific hazards) of higher incidences were studied, namely culling due to low fertility, low productivity, lameness and mortality (see Table 1). The competing risks analysis was carried out by fitting the Cox proportional hazards model to the data with appropriate censoring criteria (Dürr et al., 2002). For example, if a sow was culled at 400 days due to low productivity, her record was regarded as uncensored at 400 days in the productivity-specific analysis and as censored at 400 days in the fertility-specific, lameness-specific and mortality-specific analysis. Therefore, the number of complete and censored records was different in each cause-specific analysis: 70 complete records (15.0%) and 397 censored records (85.0%) for fertility; 200 complete records (42.8%) and 267 censored records (57.2%) for productivity; 23 complete records (4.9%) and 444 censored records (95.1%) for lameness; and 51 complete records (10.9%) and 416 censored records (89.1%) for mortality.

Table 1
Number of failures (percentages) regarding the different causes of culling throughout a sow's productive life

	Before 300 days	300–850 days	After 850 days	All life
Fertility	31 (46%)	36 (15%)	3 (6%)	70 (20%)
Productivity	0 (0%)	156 (66%)	44 (86%)	200 (56%)
Lameness	17 (25%)	6 (3%)	0 (0%)	23 (7%)
Mortality	14 (21%)	33 (14%)	4 (8%)	51 (14%)
Others	4 (8%)	5 (2%)	0 (0%)	9 (3%)
Total	66	236	51	353

The model assumed to analyse the effect of different factors influencing the cause-specific hazards was the following semiparametric proportional hazards model:

$$h_d(t) = h_{0d}(t)\exp\{X\beta\} = h_{0d}(t)\exp\{\mathrm{ADGt}_j + \mathrm{BFt}_k + \mathrm{ADGm}_n + \mathrm{BFf}_p + \mathrm{LDf}_q + \mathrm{Mf}_m\}$$

where $h_d(t)$ was the cause-specific hazard function at time t and $h_{0d}(t)$ was the cause-specific unknown baseline hazard function (d=f for fertility-specific; d=p for productivity-specific; d=l for lameness-specific; and d=m for mortality-specific analyses). In the exponential term, all effects were categorised and assumed to be time-independent (or proportional). Initially, factors were classified into five categories taking cut-off points at percentiles 20, 40, 60 and 80 (Table 2). After that, categories with a similar effect were grouped. The average daily gain from birth to the end of the growth test, ADGt_j, had two categories, under and over 585 g/day. The backfat thickness at the end of the growth test, BFt_k, also had two categories, under and over 16 mm. The average daily gain from the end of the growth test to mating, ADGm_n, had three categories with cut-off points at 325 g/day and 485 g/day. Backfat thickness at first farrowing, BFf_p, also had three categories with cut-off points at 15 mm and 19 mm. Loin depth at first farrowing, LDf_q, had four categories with cut-off points at 40 mm, 45mm and 50 mm. Finally, month at first farrowing, Mf_m, had five categories: December, January, February, March and April.

The proportional hazards assumption was tested by extending the proportional hazards model with time-dependent factors, i.e., interaction terms between the time-independent (or proportional) factor and a function of time (changing at 300 and 850 days). The proportional hazards assumption was checked via likelihood ratio tests (LRT) comparing the proportional model with models including one time depen-

Table 2
Cut-off points for the factor variables affecting longevity in the competing risk analysis

	Percentiles			
	20	40	60	80
ADGt (g/day)	560	585	610	635
BFt (mm)	12.5	14	16	17.5
ADGm (g/day)	325	375	420	485
BFf (mm)	15	17	19	21
LDf (mm)	40	45	50	

Average daily gain (ADGt) and backfat thickness (BFt) until the end of the growth test, average daily gain (ADGm) from the test to first mating, backfat thickness (BFf) and loin depth (LDf) at first farrowing.

dent factor at a time. The inclusion of these interaction terms did not increase the likelihood significantly in any of the models analyzed (results not shown in tables), and, thus, the proportionality hypothesis was not rejected. This implies that the estimated β-coefficients for each proportional factor are equivalent to the effect of the variable throughout the period analyzed (Allison, 1995).

2.2.2. Non-specific analysis

A factor that had a different effect depending on the cause-specific hazard may have a different effect on a non-specific hazard in the different periods of productive life (see Table 1). In this sense, to analyse the different effects of factors throughout the productive life, a time-dependent semiparametric proportional hazard model was assumed:

$$h(t) = h_0(t)\exp\{X\beta\}$$
$$= h_0(t)\exp\{\mathrm{ADGt}_j + \mathrm{BFt}_k + \mathrm{ADGm}_n + \mathrm{BFf}_p + \mathrm{LDf}_q + \mathrm{Mf}_m\}$$

where $h(t)$ was the non-specific hazard function at time t and $h_0(t)$ was the unknown non-specific baseline hazard function. The exponential term had the same covariates and categories as in the previous model. However, in this model some effects were time-dependent and therefore changed after a specific cut-off point. Initially, three periods were analysed with cut-off points at 300 days and 850 days. If the effect did not change from one period to the next, these two periods were grouped. The effect of average daily gain during the growth test, ADGt_j, changed at 850 days of productive life, whereas backfat thickness at the end of the growth test, BFt_k, and loin depth at first farrowing, LDf_q, changed at 300 days of productive life (i.e., after completing two farrowings). Finally, the effects of average daily gain between the end of the growth test and first mating, ADGm_n, backfat thickness at first farrowing, BFf_p, and the month at first farrowing, Mf_m, did not change at any time so, therefore, were time-independent (or proportional) covariates. This model and the one presented in the previous section were analysed with the "Survival Kit v 3.12" (Ducrocq and Sölkner, 1998).

2.2.3. Hazard ratios

Once the β-coefficients of each factor have been estimated by maximising the partial likelihood, the hazard ratio (HR) of animals having a particular value with respect to the baseline hazard is estimated as $\mathrm{HR}=\exp\{X\beta\}$. In the time-dependent analysis, different hazard ratios were obtained in different periods of productive life, whereas in the competing risks analysis, hazard ratios were obtained for each of the disposal causes.

2.2.4. Expected survival functions

The baseline survival function $\hat{S}_0(t)$ was computed by an empirical approach similar to the one leading to the Kaplan–Meier estimate (Kaplan and Meier, 1958). This empirical baseline survival function also allowed us to obtain the expected survival function in a hypothetical herd with all sows having a particular sequence of values by:

$$S(t_i, X) = [S_0(t_i)]^{HR}$$

This formula works for time-independent variables. When time-dependent variables were analysed, the hazard ratio HR_1 before the cut-off point c_1 was different from the hazard ratio HR_2 after it. Therefore, the survival function was also different before: $S(t_i,X)=[S_0(t_i)]^{\mathrm{HR}_1}$, and after the cut-off point c_1:$S(t_i,X) = \frac{[S_0(c_1)]^{HR_1}[S_0(t_i)]^{HR_2}}{[S_0(c_1)]^{HR_2}}$.

2.2.5. Replacement rate

The replacement rate (RR) is the ratio between the number of animals entering the herd n, and the number of animals in the herd N; thus, the replacement rate associated with any expected survival function assuming constant herd size is (Tarrés et al., 2004):

$$RR(k,X) = \frac{n}{N} = \frac{1}{\sum_{i=0}^{k} (S(t_i,X)\mathrm{d}t_i)}$$

This formula was used to compute RR's from an empirical survival function. The upper bound of the k productive life interval (t_k, u) was the longest desired utilisation time of sows, u, which in our study was assumed to be 950 days.

3. Results

3.1. Competing risks analysis

In the competing risks analysis, hazard ratios were obtained for each of the disposal causes: fertility, productivity, lameness and mortality (Fig. 1). These cause-specific hazard ratios are, however, not comparable among different causes of culling because each type-specific baseline hazard function is different.

A sow was culled due to low fertility after failing to cycle twice consecutively. Sows with an average daily gain during growth test higher than 585 g/day reduced the risk of culling due to fertility ($P<0.05$) (Fig. 1a). Nevertheless, after the end of the test period, higher average daily gains until first mating tended to increase this specific culling ($P<0.10$).

After the third weaning, sows with an average litter size weaned at fewer than 7.5 piglets were culled because of low productivity. Backfat thickness at the end of the growth test of less than 16 mm increased this type of culling ($P<0.05$) (Fig. 1b). Culling due to low productivity also increased with loin depth at first farrowing ($P<0.05$). Finally, higher average daily gains from the end of the growth test to the first mating also tended to have

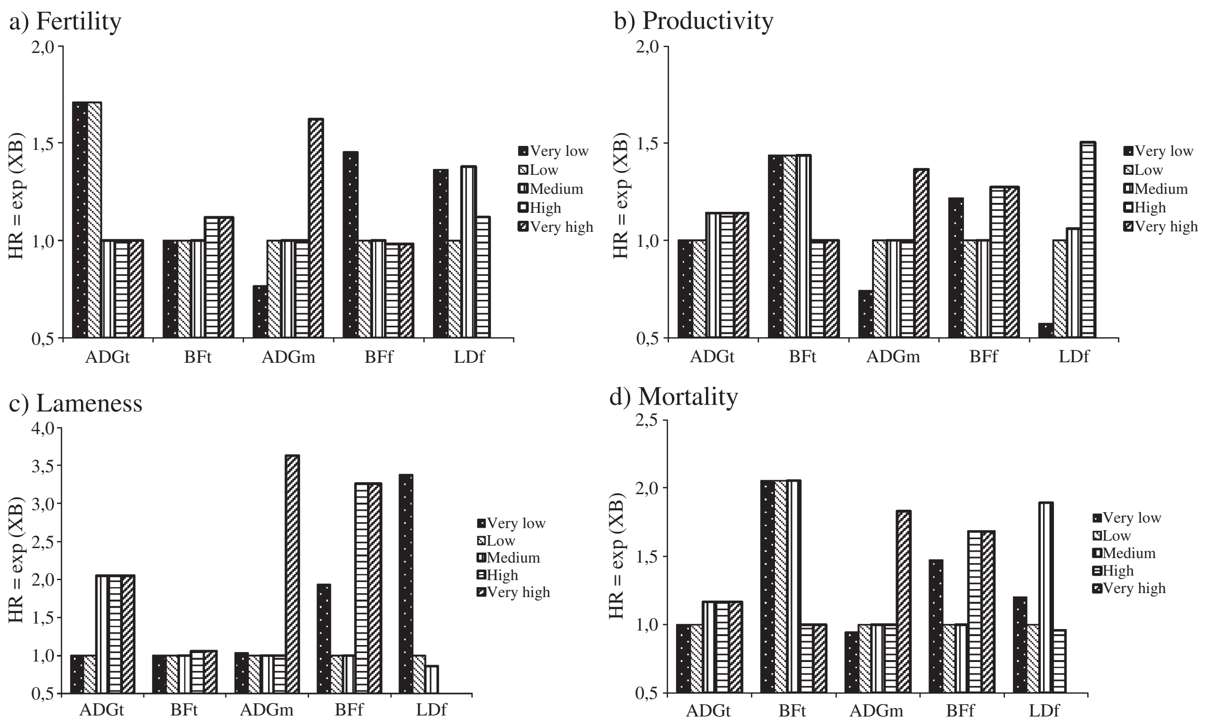

Fig. 1. Relative hazard ratios of culling due to different causes (competing risk analysis) for different average daily gain values during the growth test (ADGt), average daily gain from test to mating (ADGm), backfat thickness at the end of growth test (BFt), backfat thickness at first farrowing (BFf), and loin depth at first farrowing (LDf). Each category (very low, low, medium, high, very high) includes 20% of data; see cut-off points in Table 2.

some influence on increasing culling due to productivity ($P<0.10$).

Apart from their fertility and productivity, sows with signs of lameness were culled after weaning their piglets. Culling due to lameness increased with average daily gains from the end of the growth test to first mating greater than 485 g/day ($P<0.05$), backfat thickness at first farrowing more than 19 mm ($P<0.05$) and loin depth at first farrowing less than 40 mm ($P<0.05$) (Fig. 1c).

The hazard ratios of different factors affecting mortality are shown in Fig. 1d. Backfat thickness at the end of the growth test less than 16 mm increased mortality in Duroc sows ($P<0.05$). Mortality also increased with large loin depths at first farrowing ($P<0.05$). Furthermore, higher average daily gains from the end of the growth test to first mating also had some effect on increasing mortality ($P<0.10$).

In summary, culling due to low fertility increased if the gilt did not achieve an average daily gain during the growth test of 585 g/day. Culling due to low productivity and mortality increased with low levels of backfat thickness at the end of the growth test. Lesser loin depths at first farrowing reduced culling due to low productivity but increased culling due to lameness. Nevertheless, higher average daily gain from the end of the growth test to first mating increased all causes of culling in a similar way and, therefore, this was the main factor that should be monitored to improve any cause-specific culling.

3.2. Non-specific cause analysis

Culling is a composite trait that results from several causes. Globally, the main causes of failure were low fertility (20%), low productivity (56%), lameness (7%) and mortality (14%) (Table 1). However, the percentages of different causes of non-specific culling changed throughout a sow's productive life. One half of the sows were culled during the first 300 days of productive life due to low fertility, one quarter due to lameness and the other quarter due to mortality. In this period, there was no culling due to low productivity. But after 300 days, the main cause of culling was low productivity. From 300 days to 850 days, two thirds of the sows were culled due to low productivity, 15% due to fertility and another 15% due to mortality. Culling due to lameness had little importance after 300 days. After 850 days of productive life, the relative importance of culling due to low productivity increased to 86% of culled sows. In this period, culling due to other causes was not important. As the relative importance of the various causes of culling was different throughout a sow's productive life, the effect of factors on culling was also expected to be different throughout her productive life.

The average daily gain during the growth test had a limited effect on the risk of culling, since only after 850 days of productive life the group of sows with gains higher than 585 g/day slightly tended to have more risk of being culled ($P<0.18$). On the other hand, average daily gain until mating of over 485 g/day increased the risk of culling ($P<0.01$) (Fig. 2a). This effect was similar along the entire productive life of the sow given that it had a similar effect on each specific culling (see Fig. 1), suggesting a negative phenotypic association between daily gain after the growth test and length of productive life.

Backfat thickness at the end of the growth test had no effect on the risk of culling until 300 days of productive life (Fig. 2b). After 300 days, however, sows with reduced backfat thickness (less than 16 mm) had an increased risk of culling ($P<0.01$). On the other hand, the effect of backfat thickness at first farrowing in Duroc sows was similar through their productive life. Sows falling in the interval of 15–19 mm had the minimum risk of culling (Fig. 2c). This optimal interval of backfat thickness at first farrowing was also observed in most of the type-specific analyses (Fig. 1).

Loin depth at first parturition did not have an overall significant effect on the risk of culling, although after 300 days of productive life, sows with a greater loin depth presented a higher risk of being culled compared to the sows with a loin depth of less than 50 mm ($P<0.05$) (Fig. 2d). Finally, month at first farrowing had a significant effect on the risk of culling ($P<0.05$), but no estimates of the hazard ratios are shown because it did not follow any consistent trend.

3.3. Body type effect on the expected survival of sows

The effects of the culling factors have been assessed so far using hazard ratios which are relative measures that do not take into account the baseline

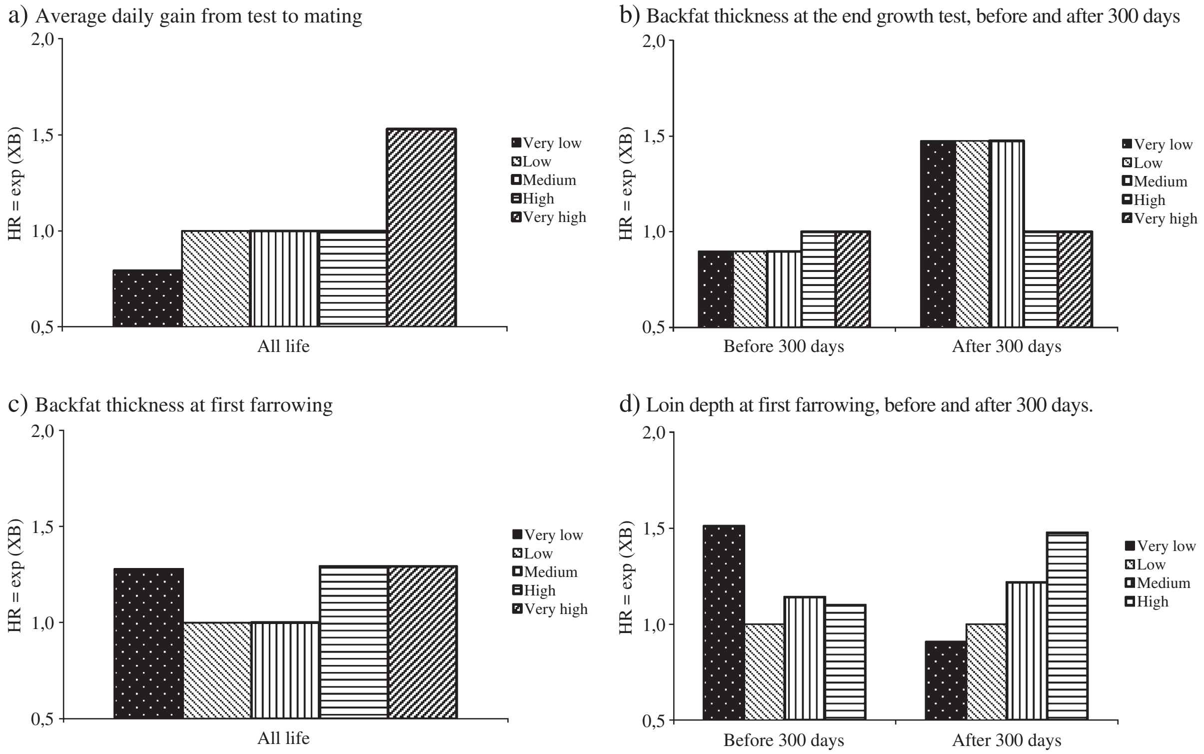

Fig. 2. Relative hazard ratios of non-specific culling at different productive life intervals. Each category (very low, low, medium, high, very high) includes 20% of data; see cut-off points in Table 2.

hazard. To obtain useful measures for future economic studies, three different hypothetical situations for body type (BT) were defined (Table 3), and the corresponding survival functions computed and compared to the observed survival function (Fig. 3). These survival functions allowed us to calculate annual replacement rates of the hypothetical herd and to compare them to the observed annual replacement rate (56.1%).

Table 3
Values describing three hypothetical situations for animal body type (BT)

	High BT	Low BT	Optimal BT
ADGt (g/day)	>585	<585	>585
BFt (mm)	>16	<16	>16
ADGm (g/day)	>485	<325	<325
BFf (mm)	>19	<15	15–19
LDf (mm)	>50	<40	<40

Average daily gain (ADGt) and backfat thickness (BFt) until the end of the growth test, average daily gain (ADGm) from the test to first mating, backfat thickness (BFf) and loin depth (LDf) at first farrowing.

The first hypothetical situation would be to maximise/increase animal body type at the end of the growth test and at first farrowing (High BT, Table 3). This strategy would keep culling due to fertility under control, but it would increase culling due to productivity, lameness and mortality excessively (Table 4). In the time-dependent analysis, sows with high body type would have a hazard ratio of about 2.2 until 300 days, 2.9 from 300 days to 850 days and 4.4 after 850 days of productive life. Therefore, sows with a high animal body type are expected to have a high risk of culling that increases as other than lower fertility causes of culling become more important. These high hazard ratios implied a lower survival function than the observed one (Fig. 3). The associated replacement rate would be 76.6%, increasing the observed one by 20%.

The opposite hypothetical situation would be to minimise/decrease animal body type at the end of

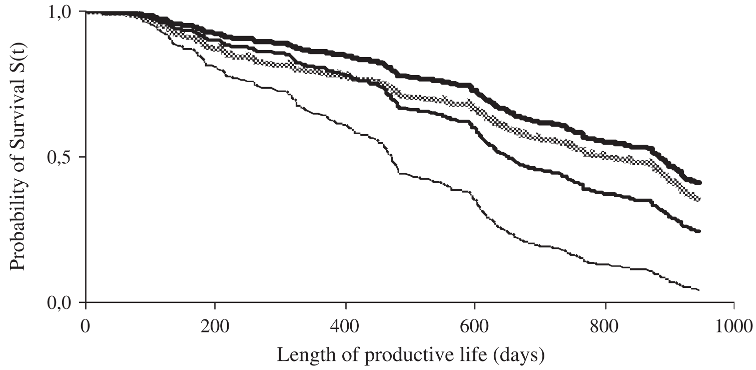

Fig. 3. Expected survival functions under different animal body types (high ___, low and optimal) compared to the Kaplan–Meier estimate .

the growth test and at first farrowing (Low BT, Table 3). This strategy would improve culling due to productivity, but it would slightly increase culling due to fertility and excessive culling due to lameness and mortality (Table 4). In the non-specific cause analysis, sows with the lowest animal body type would have a similar hazard ratio of about 1.37 throughout productive life. These proportional hazard ratios implied a higher survival function than the observed one (Fig. 3). The associated replacement rate would be 52.3%, reducing the observed one by 4%.

A third hypothetical situation (Optimal BT in Table 3) would be to maximise/increase animal body type at the end of the growth test and then to minimise/decrease it at first farrowing, but maintaining the backfat thickness between 15 mm and 19 mm. This strategy would specially improve culling due to fertility and productivity and maintain mortality under control, but it would excessively increase lameness problems (Table 4). In the non-specific time-dependent analysis, sows under this hypothesis would have a hazard ratio about 1.2 until 300 days, 0.73 from 300 days to 850 days and 1.1 after 850 days (Table 4). Therefore, sows with the optimal animal body type had a low risk of culling that was only slightly higher during the first 300 days when lameness had more relative influence on the risk of culling. Lameness problems under this hypothesis were associated with shallow loin depth at first farrowing, but shallow loin depths were needed to minimise culling due to low productivity and mortality that had more relative importance in the risk of culling. The associated replacement rate would be 48.8%, reducing the observed one by 7%, which shows the superiority of this body type to increase a sow's productive life and reduce the costs associated with higher culling rates.

Table 4
Relative hazard ratios (HR) for competing risks and for time-dependent analyses and annual replacement rates (RR) under hypothetical situations of body type (BT)

	High BT	Low BT	Optimal BT
$HR_{Fertility}$	1.044[a]	1.356	0.610
$HR_{Productivity}$	2.979	0.739	0.482
$HR_{Lameness}$	11.899	6.391	7.161
$HR_{Mortality}$	3.440	3.425	1.322
$HR_{0–300\ days}$	2.202	1.379	1.217
$HR_{300–850\ days}$	2.957	1.363	0.731
$HR_{After\ 850\ days}$	4.420	1.363	1.093
RR	76.6%	52.3%	48.8%

[a] The hazard ratio of reference for each value is that of the corresponding baseline.

4. Discussion

The pre-farrowing factors analysed significantly influenced culling in Duroc sows. In some cases the effect was clearly time-dependent, in part because the effect of the factors on longevity depends upon the relative importance of the different causes of culling that change throughout time. Until 300 days of productive life (first and second farrowings), the most important factors are those that affect fertility, lameness and mortality. After the third farrowing, factors affecting productivity become the most important. As productivity was the cause with the greatest weight in culling (56% of total losses), the factors that affect productivity were those with a greater effect on the culling rate. Of the remaining losses 20% were due to low fertility, 7% to lameness and 14% to mortality. These results are within the ranges reported previously by other authors (Lopez-Serrano et al., 2000). Another research by Dijkhuizen et al. (1989) has also shown the evolution of the factors influencing culling throughout time. These authors describe that the most important causes of culling in gilts are lameness and fertility, whereas low productivity becomes more important after the second-third farrowing.

Average daily gains during the growth test higher than 585 g/day reduced culling due to fertility. This fact is consistent with the improvement in re-mating and farrowing rates with increasing growth rates observed by Tummaruk et al. (2001) in Landrace and Yorkshire. However, in general, average daily gain during the growth test had little effect on the risk of culling in Duroc sows. This is in agreement with recent studies on the Landrace breed (Yazdi et al., 2000; Lopez-Serrano et al., 2000), although Lopez-Serrano et al. (2000) observed a significant, unfavourable genetic correlation between daily gain and stayability in Large White, in accordance with the results of Tholen et al. (1996) and Brandt et al. (1999) in two crossbreeds. These breed differences could be based on physiological causes linked to differences in selection strategies.

The main factor that should be monitored before the end of the growth test is backfat thickness. Sows with backfat thickness less than 16 mm showed a higher risk of culling due to low productivity and mortality. These results are in agreement with those of Tummaruk et al. (2001) in Landrace and Yorkshire, who observed that thinner sows had a lower number of piglets born and born alive, although Hermesch et al. (2000) did not find this relationship. In addition, our results showed that backfat thickness at the end of the growth test of less than 16 mm increased the risk of culling after the third farrowing, mainly due to low productivity. These results are in agreement with those of O'Dowd et al. (1997), Lopez-Serrano et al. (2000) and Tholen et al. (1996), who observed a positive association between backfat thickness at test and survival of sows. However, a recent study based on the Landrace breed has reported that backfat thickness at test does not influence longevity of sows (Yazdi et al., 2000).

After the end of the growth test, our results suggest the importance of limiting average daily gain until first mating. The risk of culling due to each specific cause was increased by average daily gains over 485 g/day, having a similar strong effect throughout the sow's entire productive life. Therefore, average daily gain from test to first mating is the most important factor that should be monitored to improve longevity of sows. Two potential causes could be suggested to explain this negative phenotypic association between daily gain and length of productive life. On the one hand, a higher average daily gain may be associated with a higher level of fat deposition and this, in turn, would lead to a lower fertility and higher culling rate. On the other hand, it has been suggested that a high feeding level during the growing phase in gilts could be associated with leg weakness in the later stages of their productive life and, thus, a higher culling rate (Jørgensen and Sørensen, 1998). Both of these observations are in agreement with our findings, where a high average daily gain led to higher culling rates due to fertility and lameness.

As mentioned above, backfat thickness at the end of the growth test should be over 16 mm. This level of backfat thickness should be maintained at first farrowing within the interval of 15–19 mm to have the minimum risk of culling. Backfat thickness at first farrowing higher than 19 mm significantly increased the risk of culling. On the other hand, backfat thickness under 15 mm tended to increase culling due to lameness. In this sense, some influence of backfat thickness on longevity could be explained through leg weakness syndrome as a consequence of less backfat thickness, as has previously been described by different authors (see review in Lopez-Serrano et al., 2000). Elsley and Shirlaw (1976) stated that body reserves at the beginning of the breeding life represented the most important factor in explaining differences in performance in sows; for which a feeding strategy for the breeding herd should include targeted fat reserves for the gilt, and subsequent work (Whittemore et al., 1988; Yang et al., 1989; Gaughan et al., 1995) has supported this argument.

Finally, loin depth at first farrowing had a different effect on the risk of culling at different intervals of productive life. Whilst the cause of culling was not productivity (i.e. before 300 days of age), loin depths less than 40 mm were associated with a higher risk of culling due to greater lameness problems. From 300 days of age on, when productivity became the main cause of culling, sows with a loin depth over 50 mm presented a higher risk of being culled, mainly due to low productivity and mortality. A link between increased genetic leanness in commercial genotypes and a progressive increase in both culling and mortality rate may exist (Edwards, 1995). Also, negative consequences for reproductive performance of these genetic changes have been reported in contemporary comparisons of different selection lines (Kerr and Cameron, 1995), where selection for low daily food intake or high lean tissue feed conversion resulted in smaller litter size, reduced milk yield and reduced longevity. O'Dowd et al. (1997) explained this by arguing that higher genetic leanness could be correlated to greater body size and maintenance requirements.

5. Conclusions and implications

By using the methodology of survival analysis, the influence on longevity of factors such as backfat thickness, loin depth and average daily gains at different stages of life before the first farrowing has been determined. The most important factor in reducing all causes of culling is to limit the average daily gain between the end of the growth test and the first mating. Backfat thickness at first farrowing has also an optimal interval for reducing all of the causes of culling although its effect was not so great. Genetic or nutritional strategies for changing body type must pay attention to long term reproductive performance, as the replacement rates associated to different body types could differ up to 27%. This analysis suggests one possible optimal combination of these factors (optimal body type) in order to improve longevity in maternal Duroc lines. In our conditions, the optimal strategy implies the achievement of a high backfat thickness at the end of test, and afterwards to maintain optimal levels, with reduced growth rate until mating and minimal loin depth at first farrowing.

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